



US008933321B2

(12) **United States Patent**
Hadar et al.

(10) **Patent No.:** **US 8,933,321 B2**
(45) **Date of Patent:** **Jan. 13, 2015**

(54) **SYSTEMS AND METHODS FOR AN
ENHANCED WATCHDOG IN SOLAR
MODULE INSTALLATIONS**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 676 days.

(21) Appl. No.: **12/628,977**

(22) Filed: **Dec. 1, 2009**

(65) **Prior Publication Data**

US 2010/0139734 A1 Jun. 10, 2010

Related U.S. Application Data

(60) Provisional application No. 61/275,977, filed on Sep.
3, 2009, provisional application No. 61/276,753, filed
on Sep. 16, 2009.

(51) **Int. Cl.**
H01L 31/042 (2014.01)
H01L 31/048 (2014.01)
H01L 31/02 (2006.01)

(52) **U.S. Cl.**
CPC **H01L 31/0485** (2013.01); **H01L 31/02021**
(2013.01); **Y02E 10/50** (2013.01)
USPC **136/244**; 136/243; 136/245; 136/246;
136/247; 136/248; 136/250; 136/251; 200/506;
439/135; 439/150; 439/152; 439/160

(58) **Field of Classification Search**
USPC 136/243, 244, 251; 307/19, 20, 64–66
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,580,090	A	4/1986	Bailey et al.
4,604,567	A	8/1986	Chetty
4,873,480	A	10/1989	Lafferty
5,027,051	A	6/1991	Lafferty
5,143,556	A	9/1992	Malin
5,235,266	A	8/1993	Schaffrin
5,268,832	A	12/1993	Kandatsu
5,280,133	A	1/1994	Nath
5,504,418	A	4/1996	Ashley
5,604,430	A	2/1997	Decker et al.

(Continued)

FOREIGN PATENT DOCUMENTS

AU	2005262278	7/2005
DE	4232356	3/1994

(Continued)

OTHER PUBLICATIONS

Wiles et al., "Photovoltaic Power Systems and the National Electrical
Code", Sandia, 1999.*

(Continued)

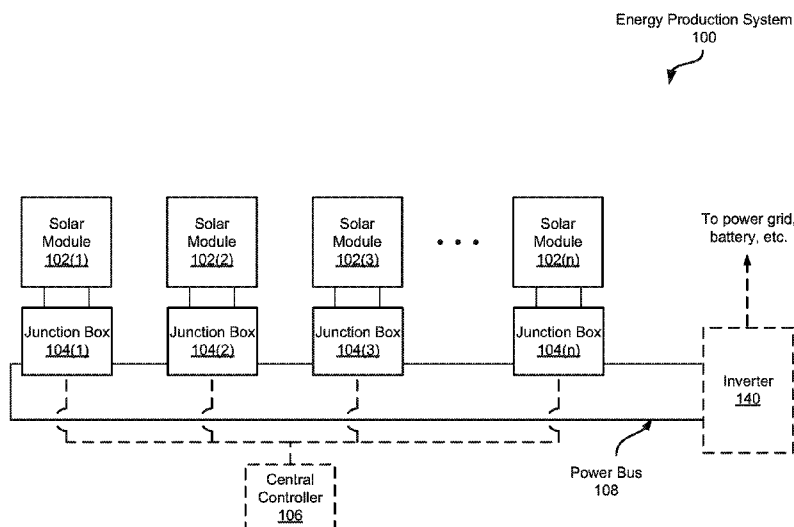
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(57) **ABSTRACT**

Systems and methods are disclosed for automatically or remotely rendering a solar array safe during an emergency or maintenance. A watchdog unit is disclosed for monitoring a signal from a central controller. If the signal is lost, interrupted, or becomes irregular, or if a shutdown signal is received, then the watchdog unit can shutdown one or more solar modules. Shutting down a solar module can mean disconnecting it from a power bus of the solar array or lowering the solar module voltage to a safe level.

20 Claims, 5 Drawing Sheets



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(56)

References Cited

U.S. PATENT DOCUMENTS

5,648,731	A	7/1997	Decker et al.	
5,747,967	A	5/1998	Muljadi et al.	
5,923,158	A	7/1999	Kurokami et al.	
5,932,994	A	8/1999	Jo et al.	
6,031,736	A	2/2000	Takehara et al.	
6,093,885	A	7/2000	Takehara et al.	
6,101,073	A *	8/2000	Takehara	361/42
6,275,016	B1	8/2001	Ivanov	
6,396,239	B1	5/2002	Benn et al.	
6,448,489	B2	9/2002	Kimura et al.	
6,515,215	B1	2/2003	Mimura	
6,545,211	B1	4/2003	Mimura	
6,593,520	B2	7/2003	Kondo et al.	
6,650,031	B1	11/2003	Goldack	
6,653,549	B2	11/2003	Matsushita et al.	
6,837,739	B2	1/2005	Gorringer et al.	
6,844,739	B2	1/2005	Kasai et al.	
6,894,911	B2	5/2005	Telefus et al.	
6,897,370	B2	5/2005	Kondo et al.	
6,984,970	B2	1/2006	Capel	
7,061,214	B2	6/2006	Mayega	
7,150,938	B2	12/2006	Munshi et al.	
7,248,946	B2	7/2007	Bashaw et al.	
7,256,566	B2	8/2007	Bhavaraju et al.	
7,259,474	B2	8/2007	Blanc	
7,276,886	B2	10/2007	Kinder	
7,336,004	B2	2/2008	Lai	
7,394,237	B2	7/2008	Chou et al.	
7,462,955	B2	12/2008	McNamara	
7,518,266	B2	4/2009	Eckroad	
7,518,346	B2	4/2009	Prexl	
7,538,451	B2	5/2009	Nomoto	
7,545,053	B2	6/2009	Yoshikawa	
7,595,616	B2	9/2009	Prexl	
7,602,080	B1	10/2009	Hadar et al.	
7,605,498	B2	10/2009	Ledenev et al.	
7,719,140	B2	5/2010	Ledenev et al.	
7,807,919	B2	10/2010	Powell et al.	
7,884,278	B2	2/2011	Powell et al.	
2005/0057214	A1	3/2005	Matan	
2005/0057215	A1	3/2005	Matan	
2005/0172995	A1	8/2005	Rohrig et al.	
2006/0001406	A1	1/2006	Matan	
2006/0174939	A1	8/2006	Matan	
2006/0185727	A1	8/2006	Matan	
2006/0231132	A1	10/2006	Neussner	
2007/0273351	A1	11/2007	Matan	
2008/0036440	A1	2/2008	Garmer	
2008/0121272	A1	5/2008	Besser et al.	
2008/0122449	A1	5/2008	Besser et al.	
2008/0122518	A1	5/2008	Besser et al.	
2008/0142071	A1 *	6/2008	Dorn et al.	136/245
2008/0147335	A1	6/2008	Adest et al.	
2008/0164766	A1	7/2008	Adest et al.	
2008/0179949	A1	7/2008	Besser et al.	
2008/0191560	A1	8/2008	Besser et al.	
2008/0191675	A1	8/2008	Besser et al.	
2008/0236648	A1 *	10/2008	Klein et al.	136/244
2008/0303503	A1	12/2008	Wolfs	
2009/0066357	A1	3/2009	Fornage	
2009/0114263	A1	5/2009	Powell et al.	
2009/0179662	A1	7/2009	Moulton et al.	
2009/0182532	A1	7/2009	Stoeber et al.	
2009/0207543	A1	8/2009	Boniface et al.	
2010/0057267	A1 *	3/2010	Liu et al.	700/297
2010/0326809	A1	12/2010	Lang et al.	
2011/0061713	A1	3/2011	Powell et al.	
2011/0172842	A1	7/2011	Makhota et al.	
2011/0218687	A1	9/2011	Hadar	

FOREIGN PATENT DOCUMENTS

DE	19961705	7/2001
DE	102005012213	1/2009

DE	102005018173	5/2009
EP	0178757	4/1986
EP	1388774	2/2004
ES	2249147	3/2006
JP	4219982	8/1992
JP	8097460	4/1996
JP	8116628	5/1996
JP	8316517	11/1996
JP	9148611	6/1997
JP	11103538	4/1999
JP	2000358330	12/2000
JP	2003134661	5/2003
KR	200402282	11/2005
KR	100725755	6/2007
KR	100912892	8/2009
WO	03012569	2/2003
WO	2005069096	7/2005
WO	2005112551	12/2005

OTHER PUBLICATIONS

Advanced Energy Group, "The Basics of Solar Power Systems," located at <http://web.archive.org/web/20010331044156/http://www.solar4power.com/solar-power-basics.html>, Mar. 31, 2001.

Definition of "removable" from Webster's Third New International Dictionary, Unabridged, 1993.

Definition of "remove" from Webster's Third New International Dictionary, Unabridged, 1993.

Hewes, J. "Relays," located at <http://web.archive.org/web/20030816010159/www.kpsec.freeuk.com/components/relay.htm>, Aug. 16, 2003.

International Patent Application No. PCT/US2008/081827, International Search Report and Written Opinion, Jun. 24, 2009.

Palma, L. et al., "A Modular Fuel Cell, Modular DC-DC Converter Concept for High Performance and Enhanced Reliability," 38th IEEE Power Electronics Specialists Conference (PESC'07), pp. 2633-2638, Jun. 17, 2007.

Quaschnig, V. et al., "Cost Effectiveness of Shadow Tolerant Photovoltaic Systems," Euronsun 96, pp. 819-824, Sep. 16, 1996.

Uriarte, S. et al., "Energy Integrated Management System for PV Applications," 20th European Photovoltaic Solar Energy Conference, Jun. 6, 2005.

Walker, G. R. et al., "Cascaded DC-DC Converter Connection of Photovoltaic Modules," 33rd IEEE Power Electronics Specialists Conference (PESC'02), vol. 1, pp. 24-29, 2002.

Alonso, R. et al., "A New Distributed Converter Interface for PV Panels," 20th European Photovoltaic Solar Energy Conference, Barcelona, Spain, pp. 2288-2291, Jun. 6-10, 2005.

Alonso, R. et al., "Experimental Results of Intelligent PV Module for Grid-Connected PV Systems," 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, pp. 2297-2300, Sep. 4-8, 2006.

Basso, Tim, "IEEE Standard for Interconnecting Distributed Resources With the Electric Power System," IEEE PES Meeting, Jun. 9, 2004.

Boostbuck.com, "The Four Boostbuck Topologies," located at <http://www.boostbuck.com/TheFourTopologies.html>, 2003.

Enslin, Johan H.R., et al., "Integrated Photovoltaic Maximum Power Point Tracking Converter," IEEE Transactions on Industrial Electronics, vol. 44, No. 6, pp. 769-773, Dec. 1997.

Gautam, Nalin K. et al., "An Efficient Algorithm to Simulate the Electrical Performance of Solar Photovoltaic Arrays," Energy, vol. 27, No. 4, pp. 347-361, 2002.

Linares, Leonor et al., "Improved Energy Capture in Series String Photovoltaics via Smart Distributed Power Electronics," 24th Annual IEEE Applied Power Electronics Conference and Exposition, pp. 904-910, Feb. 15, 2009.

Nordmann, T. et al., "Performance of PV Systems Under Real Conditions," European Workshop on Life Cycle Analysis and Recycling of Solar Modules, The "Waste" Challenge, Brussels, Belgium, Mar. 18-19, 2004.

Roman, Eduardo, et al., "Intelligent PV Module for Grid-Connected PV Systems," IEEE Transactions on Industrial Electronics, vol. 53, No. 4, pp. 1066-1073, Aug. 2006.

US 8,933,321 B2

Page 3

(56)

References Cited

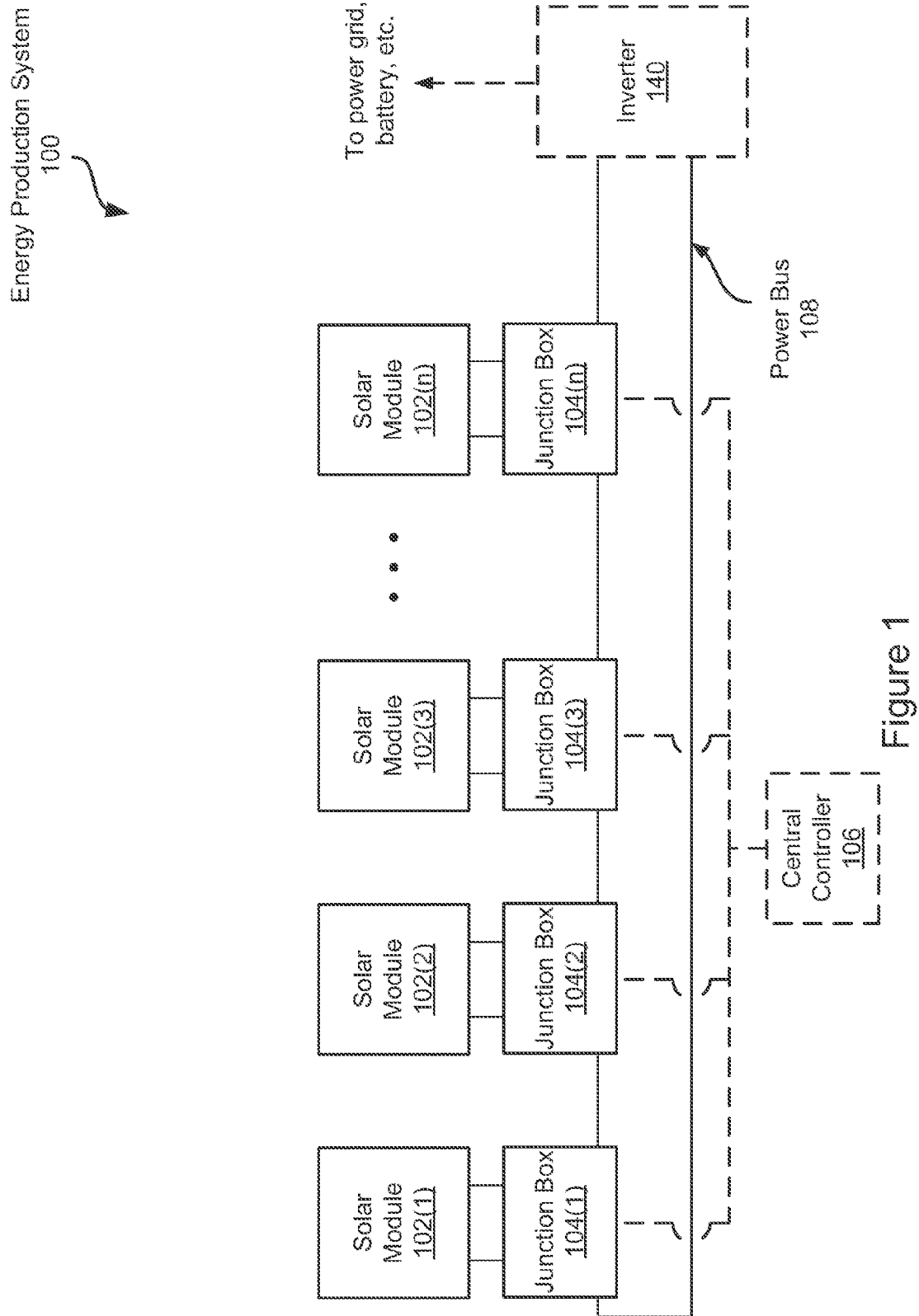
OTHER PUBLICATIONS

Walker, Jeffrey R. et al., "Cascaded DC-DC Converter Connection of Photovoltaic Modules," IEEE Transactions on Power Electronics, vol. 19, No. 4, pp. 1130-1139, Jul. 2004.

International Patent Application No. PCT/US2010/046274, International Search Report and Written Opinion, Apr. 22, 2011.

International Patent Application No. PCT/US2011/033658, International Search Report and Written Opinion, Jan. 13, 2012.

* cited by examiner



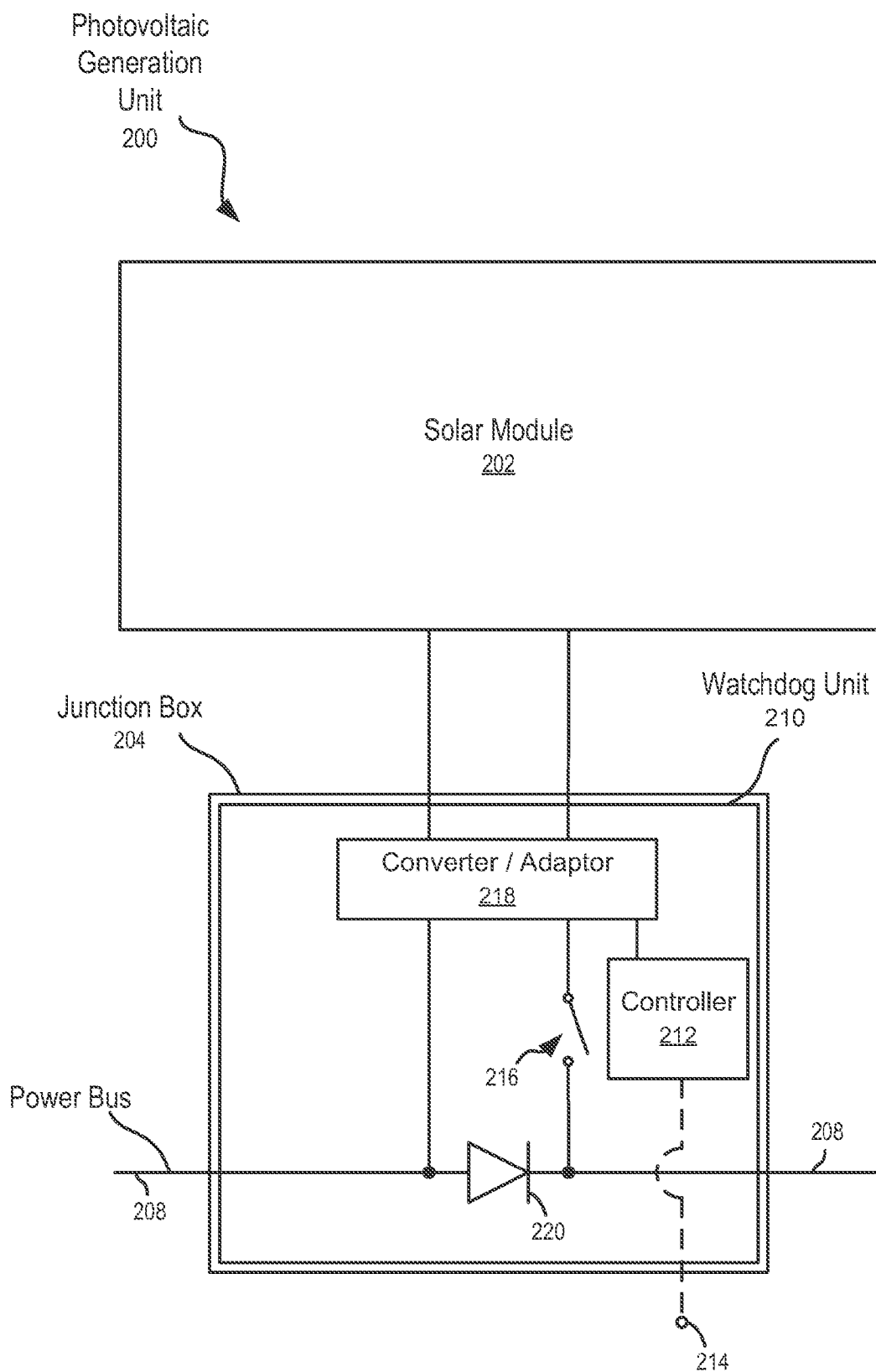
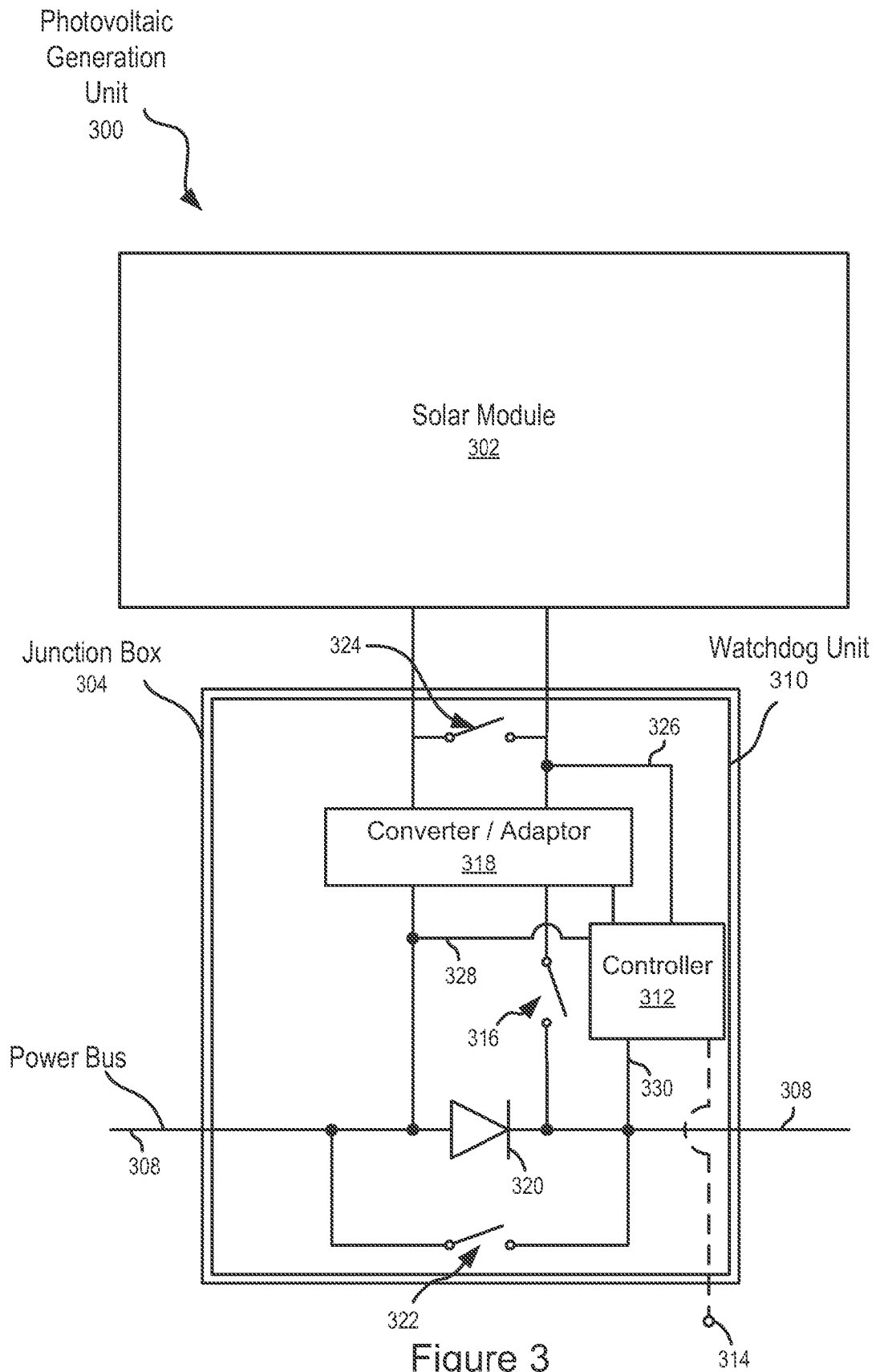


Figure 2



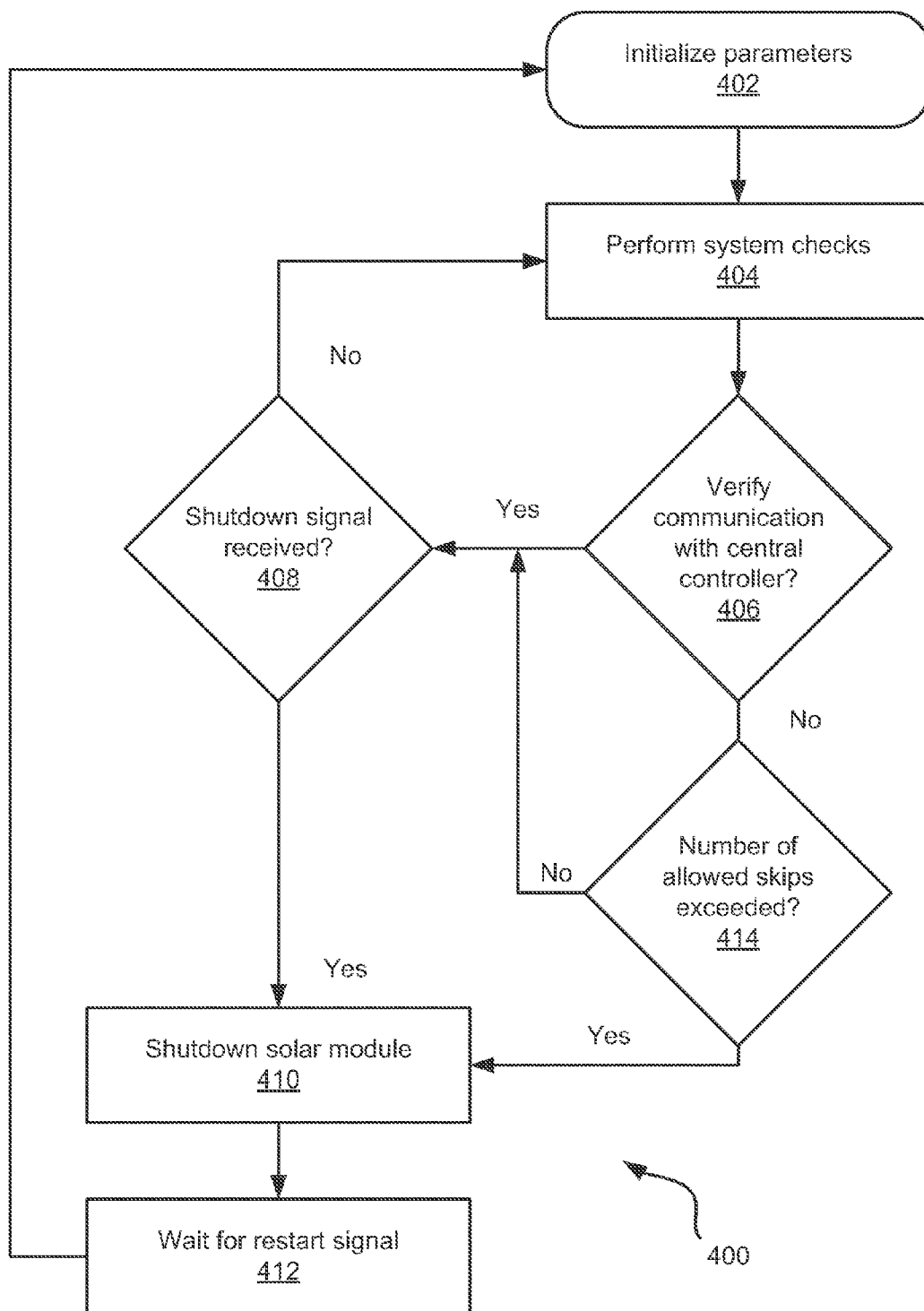
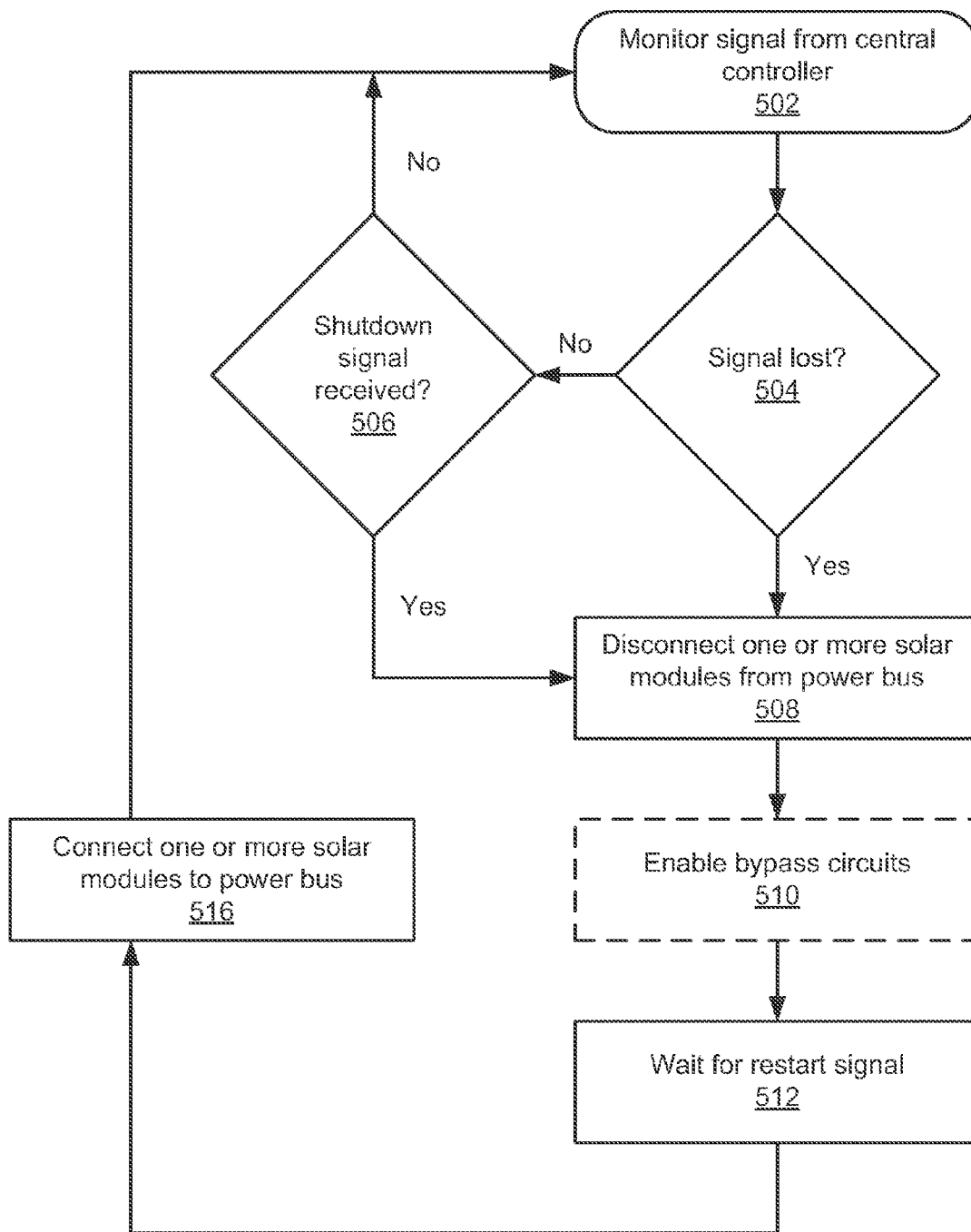


Figure 4



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Figure 5

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SYSTEMS AND METHODS FOR AN ENHANCED WATCHDOG IN SOLAR MODULE INSTALLATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of Provisional U.S. Application Ser. No. 61/275,977, filed Sep. 3, 2009, entitled "SYSTEM AND METHOD FOR ENHANCED WATCHDOG IN SOLAR PANEL INSTALLATIONS," and Provisional U.S. Application Ser. No. 61/276,753, filed Sep. 16, 2009, entitled "SYSTEM AND METHOD FOR ENHANCED WATCHDOG IN SOLAR PANEL INSTALLATIONS," the disclosures of which are hereby incorporated herein by reference.

The following applications are also incorporated herein by reference: U.S. patent application Ser. No. 12/366,597, filed Feb. 5, 2009, entitled "APPARATUSES AND METHODS TO REDUCE SAFETY RISKS ASSOCIATED WITH PHOTOVOLTAIC SYSTEMS," and U.S. patent application Ser. No. 12/411,317, filed Mar. 25, 2009, entitled "ENHANCED SYSTEM AND METHOD FOR BALANCING SOLAR PANELS IN A MULTI-PANEL SYSTEM."

FIELD OF THE TECHNOLOGY

At least some embodiments of the disclosure relate to photovoltaic systems in general, and more particularly but not limited to, improving the safety of photovoltaic systems.

BACKGROUND

First responders, solar array installers, and maintenance personnel operating near solar arrays can be exposed to dangerous or lethal voltages. The danger can be even higher if certain wires are disconnected through theft, vandalism, accident, natural forces, or other causes. To protect first responders, solar array installers, and maintenance personnel, solar arrays can be turned off in an emergency. However, the systems used to turn off a solar array in an emergency can also be disabled by the emergency (e.g., fire).

SUMMARY OF THE DESCRIPTION

Systems and methods in accordance with the present invention are described herein. Some embodiments are summarized in this section. The present disclosure relates to systems, methods, and apparatus for shutting down a photovoltaic energy generating unit when communication with a central controller is interrupted. In one approach a solar array may include a watchdog unit able to disconnect a solar module from a power bus, or lower the solar module voltage to a safe level, when communication from the central controller is interrupted. Disconnecting the solar module, or lowering the solar module voltage, may be performed by opening a switchable connection or lowering a duty cycle of the switchable connection. Either of these operations can be controlled by a controller within the watchdog unit. In an embodiment, the watchdog unit may lose power or not have access to its primary energy source (e.g., due to fire, vandalism, or malfunction, to name a few). In such an instance the watchdog unit may turn to a backup energy source (e.g., battery or capacitor).

One aspect of the disclosure is a system comprising a watchdog unit coupled between a solar module and a power bus. The watchdog unit may be configured to monitor com-

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munication from a central controller. The watchdog unit may also be configured to determine that the communication is interrupted. The watchdog unit may also be configured to disconnect the solar module from the power bus when the communication is interrupted.

Another aspect of the disclosure is a system comprising a watchdog device coupled between a solar module and a power bus. The watchdog device may be configured to verify communication with a central controller. The watchdog device may also be configured to shutdown the solar module if communication with the central controller cannot be verified.

Another aspect of the disclosure is a computer-implemented method. The method includes monitoring, via a computing device, a signal from a central controller. The method includes determining, via the computing device, if the signal has been lost. The method includes disconnecting, via the computing device, one or more solar modules from a power bus if the signal has been lost. The method includes determining, via the computing device, if the signal includes a shutdown command. The method includes disconnecting, via the computing device, the one or more solar modules from the power bus if the signal includes a shutdown command. The method includes waiting, via the computing device, for a restart signal. The method includes connecting, via the computing device, the one or more solar modules to the power bus when the restart signal is received.

Other embodiments and features of the present invention will be apparent from the accompanying drawings and from the detailed description which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments are illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements.

FIG. 1 illustrates an embodiment of an energy production system including a plurality of junction boxes each coupled between a solar module and a power bus.

FIG. 2 illustrates a solar module and a detail view of an embodiment of a junction box.

FIG. 3 illustrates an embodiment of a junction box.

FIG. 4 illustrates an embodiment of a method of controlling the output of a solar module.

FIG. 5 illustrates another embodiment of a method of controlling the output of a solar module.

DETAILED DESCRIPTION

The following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding. However, in certain instances, well known or conventional details are not described in order to avoid obscuring the description. References to one or an embodiment in the present disclosure are not necessarily references to the same embodiment; and, such references mean at least one.

Solar arrays can be shutdown during an emergency, maintenance, or installation in order to protect first responders, solar array installers, and maintenance personnel from shock or electrocution. However, systems used to shutdown a solar array can also be damaged in an emergency. The systems and methods herein disclosed can shutdown a solar array or lower the voltages to safe levels even when the solar array is damaged or when an active shutdown signal is sent to the solar array. Specifically, a watchdog unit is disclosed that monitors communication from a central controller, and upon interrup-

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tion of that communication, disconnects a solar module from a power bus. Alternatively, when communication is interrupted, the watchdog unit can lower the solar module voltage to a safe level. The systems and methods also describe a watchdog unit able to receive a shutdown signal, which would allow first responders, solar array installers, and maintenance personnel to remotely render the solar array safe before approaching the solar array. In the event that the watchdog unit loses power, backup sources of power are also described.

FIG. 1 illustrates an embodiment of an energy production system 100 including a plurality of junction boxes 104 each coupled between a solar module 102 and a power bus 108. The solar modules 102 generate power from absorbed photons and provide this power to the power bus 108. The junction boxes 104 control the voltage provided by the solar modules 102 to the power bus 108. In an embodiment, this is done via control of one or more switchable connections within the junction boxes 104. Junction boxes 104 can disconnect the solar modules 102 from the power bus 108 or lower the voltage provided to the power bus 108. The junction boxes 104 may each comprise a watchdog unit. Each watchdog unit can monitor a communication (or signal) from a central controller 106 via wireless or wired connection. When the communication is interrupted, each watchdog unit can render its associated solar module 102 safe by disconnecting the solar module 102 from the power bus 108 or by lowering the solar module 202 voltage to a safe level.

Power from the solar modules 102 can be converted to alternating current (AC) power via an optional inverter 140, and then provided to the power grid, a battery, or other load. Given a direct current (DC) load, the inverter may be left out. The power bus 108 may be connected in parallel or series with other power buses in a combiner box (not illustrated) before the combined power is provided to the inverter 140 or a (DC) load.

Watchdog units may also be configured to respond to a shutdown signal. Upon receiving a shutdown signal from the central controller 106, the watchdog units may disconnect the solar modules 102 from the power bus 108, or they may lower the solar module 102 voltages to a safe level. The shutdown signal can be automatically generated within the central controller 106 or some other controller in communication with the central controller 106. Alternatively, the shutdown signal can be manually generated. For instance, a solar array maintenance worker may push a button connected to the central controller initiating shutdown of all solar modules so that the worker can do maintenance on the solar array without worrying about shock or electrocution.

The location of the central controller 106 is non-limiting. The central controller 106 may be remote. The central controller 106 may be a part of a combiner box or inverter 140. The central controller 106 may be a part of one of the junction boxes 104.

Although FIG. 1 illustrates a junction box 104 for each solar module 102, other embodiments may have solar modules 102 that are coupled directly to the power bus without a junction box 104. Furthermore, even where there is a junction box 104 coupled between each solar module 102 and the power bus 108, there may not be a watchdog unit in every junction box 104.

A “solar cell” is a photovoltaic device configured to absorb photons and convert them into electrical energy. A “solar module” is a device that includes at least one or more solar cells, wherein the solar cells are connected in series or in parallel. The solar cells absorb photons and convert the photons into electrical energy. A “power bus” is a conductive path connecting one or more solar modules 102 in series. A

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“watchdog unit” is a device or software implemented in hardware configured to monitor a communication from a central controller 106 and shut down, or disconnect from the power bus 108, a solar module 102 when the communication from the central controller 106 is interrupted or when a shutdown signal is received. A “signal” is an electric quantity (voltage or current or field strength) whose modulation represents coded information.

FIG. 2 illustrates a solar module 202 and a detail view of an embodiment of a junction box 204. The junction box 204 may be coupled between a solar module 202 and a power bus 208. The junction box 204 may include a controller 212 and may include a switchable connection 216 (or two or more switchable connections 216). The junction box 204 optionally includes a converter/adaptor 218 and/or optionally includes a diode 220. The junction box 204 may include a watchdog unit 210. The watchdog unit 210 may be configured to monitor a communication from the central controller 106, determine that the communication has been interrupted, and disconnect the solar module 202 from the power bus 208 or lower the solar module 202 voltage to a safe level.

The watchdog unit 210 may be configured to monitor a communication from the central controller 106 via a connection 214. The connection 214 can be wired or wireless. For a wireless communication, the watchdog unit 210 may be implemented in software. For a communication arriving via a wired connection, the watchdog 210 may be implemented in hardware. However, the watchdog unit 210 for monitoring the wired communication may also be implemented in software or in a hardware-software combination. The watchdog unit 210 for monitoring the wireless communication may also be implemented in hardware or in a hardware-software combination. The communication can take any form that can be recognized by the watchdog unit 210. For instance, the communication can be continuous or pulsed, or periodic or non-periodic.

There are numerous reasons that communication may be interrupted. For instance, the central controller 106 may fail to send a communication or the connection 214 (wired or wireless) between the central controller 106 and the watchdog unit 210 may be severed by fire, accident, or malfunction, to name a few. Whatever the cause of the interruption (or interrupted fault), the watchdog unit 210 can determine that the communication has been interrupted. In response to determining that the communication has been interrupted, the watchdog unit 210 can render its associated solar module 202 safe by disconnecting the solar module 202 from the power bus 208 or by lowering the solar module 202 voltage to a safe level. Disconnecting the solar module 202 can be performed by, for instance, forcing the switchable connection 216 to operate in an open state. Lowering the solar module 202 voltage to a safe level can be performed by, for example, lowering the duty cycle of the switchable connection 216.

There are numerous ways to determine that a communication has been interrupted. For instance, given a pulsed communication, the watchdog unit 210 may look for loss of the pulses. The watchdog unit 210 may also look for an irregular periodicity to the pulses. The watchdog unit 210 may look for a decrease in the amplitude of the pulses. Whichever one or more of these the watchdog unit 210 looks for, it will also look to see that the irregular behavior has surpassed a threshold. For example, irregularity in the periodicity of the pulses may be identified when less than a threshold number of pulses are received that have an abnormal period. As another example, an interrupted communication may be one that has dropped below a certain threshold amplitude. As another example, an interrupted communication may be one that has been irregu-

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lar for longer than a threshold period of time. In an embodiment, the watchdog unit **210** may look for a threshold of irregularity to be surpassed. These limited examples merely scratch the surface of the numerous qualities or parameters that can be monitored in order to determine that a communication has been interrupted.

While the watchdog unit **210** can be triggered by an interrupted communication, it can also be triggered by an instruction or other affirmative signal. For instance, the same communication that the watchdog unit **210** monitors for interruption, could also carry an indication (or instructions) to limit the voltage or disconnect (or shutdown) the solar module **202** from the power bus **208**. In other words, the central controller **106** can be configured to transmit a repeated or continuous communication, but it can also be configured to transmit a limited-duration shutdown signal. The watchdog unit **210** can monitor the communication for an interruption or for a shutdown signal. The shutdown signal can be initiated by an automatic control in or of the central controller **106**. The shutdown signal can also be manually initiated. The manually-initiated shutdown signal may be used by first responders, solar array installers, and maintenance personnel to remotely render the solar array safe. The manual input can be connected to the central controller **106** or can be remotely transmitted to the central controller **106**.

The watchdog unit **210** can also be triggered by detecting a fault in: the power bus **208** wiring, wiring internal to the watchdog unit **210**, or wiring internal to the junction box **204**. A fault can be detected by comparing relevant voltages, or the absence of voltages between any one or more of the following: solar modules **202**, power buses **208**, or ground, to name a few. For instance, a fault can be detected by comparing relevant voltages, or the absence thereof, between the solar module **202** and the power bus **208**. In another example, the relevant voltages, or absence thereof, could be compared between the solar module **202** and the ground.

As illustrated, the watchdog unit **210** is a part of the junction box **204**. Alternatively, the watchdog unit **210** can be located outside the junction box **204**. For instance, the watchdog unit **210** can be a part of the combiner box, the inverter **140**, or any other location downstream from the junction box **204**. The watchdog unit **210** can include any one or more of the following: the controller **212**; one or more switchable connections **216**; the converter/adaptor **218**; and the diode **220**. The watchdog unit **210** may lose power. For instance, the watchdog unit **210** may become disconnected from a primary power source (e.g., via fire). In an embodiment, the primary power source may include, for example, one or more of the following: the solar module **202**, the power bus **206**, a battery (not illustrated), or a capacitor (not illustrated). For instance, the watchdog unit **210** may be wired to draw power from either or both of the solar module **202** and the power bus **206**. A backup power source can therefore provide the watchdog unit **210** with power when the watchdog unit's **210** primary power source is not available. In other words, the watchdog unit **210** can draw energy from a backup energy source when a primary energy source is not available.

The junction box **204** may include the controller **212**. The controller **212** may monitor a communication from the central controller **106** via the wired/wireless connection **214**. The wired/wireless connection **214** can also be seen in FIG. 1 as the dashed line leading from the central controller **106** to the solar modules **102**. If the communication is interrupted, then the controller **204** may render the solar module **202** safe by either limiting the solar module **202** voltage or by disconnecting the solar module **202** from the power bus **208**. The controller **204** can control the switchable connection **216** via a

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wired or wireless connection (not illustrated). The controller **204** can control the duty cycle of the switchable connection **216**. Thus, the controller **204** can control the voltage that the solar module **202** provides to the power bus **208**. The controller **204** can also disconnect the solar module **202** from the power bus **208** by leaving the switchable connection **216** in an open state. The controller **204** can be implemented in hardware, software, or a hardware-software combination. The controller **204** may derive instructions from a storage medium such as a non-volatile storage medium (e.g., electrically erasable programmable read-only memory (EEPROM), read-only memory (ROM), flash, to name a few). This allows the controller **204** to obtain instructions even when power has been lost.

The junction box **204** may include the switchable connection **216**. The switchable connection **216** may connect and disconnect the solar module **202** to/from the power bus **208**. The switchable connection **216** may be normally closed. When the switchable connection **216** is closed, the solar module **202** is connected to the power bus **208**, and the entire voltage of the solar module **202** can be provided to the power bus **208**. However, when the switchable connection **216** is opened, the solar module **202** may be disconnected from the power bus **208** and cannot provide voltage to the power bus **208**. By opening and closing the switchable connection **216** at a particular duty cycle, a portion of the solar module's **202** voltage can be provided to the power bus **208**, in essence lowering the solar module **202** voltage to a safe level. The switchable connection **216** can be mechanical or electrical (e.g., transistors). Non-limiting examples of electrical switches include field-effect transistors (FET), metal-oxide-semiconductor FETs (MOSFET), and insulated gate bipolar-type transistors (IGBT). The function of the switchable connection **216** may be carried out elsewhere (e.g., by the inverter **140**).

The junction box **204** may include a converter/adaptor **218**. The converter/adaptor **218** acts as a local management unit ("LMU"). The LMUs may be configured to balance voltages and currents between solar modules **202** and between power buses **208**. The converter/adaptor can be implemented serially (as illustrated) or in parallel (not illustrated).

The junction box **204** may include an optional diode **220**. The diode **220** can be coupled in series with the power bus **208** and coupled in parallel with the solar module **202**. The diode **220** may be forward biased in the direction of the flow of current. As such, the diode **220** can reverse bias the solar module **202**, should the solar module **202** stop producing power. The diode **220** can prevent reversal of the solar module **202** if there are one or more weak solar modules **202** on the power bus **208**. Weak solar modules **202** are those that provide a lower current than other solar modules **202**. The diode **220** may not be desired for an AC configuration since the diode **220** can rectify an AC power signal and thus reduce the power generated by the solar module **202**.

FIG. 3 illustrates an embodiment of a junction box **304**. This embodiment of a junction box **304** is similar to the junction box **204** illustrated in FIG. 2, but with the addition of optional switchable connections **322**, **324** and optional lines **326**, **328**, **330**.

The junction box **304** may include a bypass circuit such as the one formed by switchable connection **322**. Since current may have to pass through the solar module **302** in order to pass downstream on the power bus **308**, current may stop flowing in the power bus **308** if the watchdog unit **310** disconnects one of the solar modules **302** from the power bus **308**. A bypass circuit, using the switchable connection **322**, shorts the power bus **308** through the junction box **304** such

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that current in the power bus **308** can bypass the solar module **302**. The switchable connection **322** may normally be open, but may close when the solar module **302** is disconnected from the power bus **308**. The bypass circuit can be used in combination with a diode **320**. The bypass circuit also allows current to pass through the junction box **304** without having to pass through the diode **320** or the solar module **302**. The switchable connection **322** can be a mechanical or electronic switch. Non-limiting examples of electronic switches include FETs, MOSFETs, and IGBTs. The switchable connection **322** may not be desired in a high voltage system.

The junction box **304** may include a switchable connection **324**, which can be used to increase the longevity of the solar module **302**. The switchable connection **324** may be normally open. When closed, the switchable connection **324** can short the solar module **302** to itself. This may be done when the solar module **302** is disconnected from the power bus **308**. In doing so, the solar module **302** can produce current, which may increase the solar module's **302** longevity. Shorting the solar module **302** is described in more detail in related U.S. patent application Ser. No. 12/542,632, filed Aug. 17, 2009, entitled "SYSTEMS AND METHODS FOR PREVENTION OF OPEN LOOP DAMAGE DURING OR IMMEDIATELY AFTER MANUFACTURING," which is incorporated herein by reference.

The junction box **304** may include a feed line **326** connecting the solar module **302** and the controller **312**. The feed line **326** may be configured to provide the controller **312** with power when power is lost (e.g., when the controller **312** cannot obtain power from its primary power source). The junction box **304** may include a line **328** configured to provide power to the controller **312** from the solar module **302**. The junction box **304** may include a line **330** configured provide power to the controller **312** from the power bus **308**. The controller **312** may also be powered by a batter or capacitor (not illustrated).

FIG. 4 illustrates an embodiment of a method of controlling the output of a solar module. The method **400** may be computer-implemented, and each of the operations discussed below can be carried out via a computing device. The method **400** begins by initializing parameters in an initialize parameters operation **402**. System checks are then performed in a perform system checks operation **404**. The method **400** then verifies communication with a central controller via a verify communication decision **406**. If communications with the central controller are verified, then the method **400** looks for a shutdown signal in a shutdown signal received decision **408**. If a shutdown signal is not received, then the method returns to the perform system checks operation **404**. If a shutdown signal is received, then the method **400** shuts down the solar module in shutdown operation **410**. The method **400** then waits for a restart signal from the central controller in the wait for restart signal operation **412**. Once the restart signal is received, the method returns to the initialize parameters operation **402**.

Turning back to the verify communication decision **406**, if communication with the central controller is not verified, then the method **400** waits to verify communication. If communication is verified in less than an allowed number of "skips," as determined by a number of allowed skips exceeded decision **414**, then the method **400** looks for a shutdown signal in the shutdown decision **408**. The method **400** then continues from the shutdown decision **408** as previously described. However, if communication is not verified by the time the number of skips is exceeded, as determined by the number of allowed skips exceeded decision **414**, then the method **400** turns to the shutdown operation **410** and shuts the solar module down

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(disconnects one or more solar modules from the power bus or lowers one or more solar module voltages to safe levels). The method **400** then continues from the shutdown operation **410** as previously described.

The method **400** begins with the initialize parameters operation **402**. Parameters are used in the perform system checks operation **404**, as reference points for the system checks. Parameters can thus include values describing any of the systems or devices that the perform system checks operation **404** may look at. For instance, the types of wiring, proper voltages in the wires, proper currents in transistors, expected signals from the central controller, number of allowed skips, what the shutdown signal looks like, and how much time can elapse before an irregular signal is considered interrupted are just some of the parameters that can be used. Parameters can be stored in a storage medium, preferably a non-volatile storage medium such as electrically erasable programmable read-only memory (EEPROM), read-only memory (ROM), and flash.

The method **400** then performs system checks in the perform operation **404**. System checks compare the parameters to measured values. Some non-limiting examples of things that can be measured include, types of wiring, voltages in the wires, currents in transistors, signals from the central controller, number of skips, the shutdown signal, and elapsed time of interrupted signals, to name a few. For instance, a parameter initialized in the initialize operation **402** may indicate that the voltage produced by the panel should be around 30V plus or minus 5V. If the system check finds the voltage to be 29V, then everything is acceptable. However, if the voltage were 24V or any other value below 25V, then the system check might provide a warning to the central controller or take some other remedial action.

Once system checks have been performed, the method **400** tries to verify communication with the central controller in the verify decision **406**. Verifying communication includes monitoring a communication from the central controller and ensuring that there are no problems with the communication. For instance, ensuring that the voltage of the communication is above a certain threshold (e.g., within 10% of maximum power), ensuring that a certain number of pulses are received within a certain period of time (e.g., at least one hundred pulses per second), or ensuring that communication is not lost for longer than a threshold period of time (e.g., communication is not verified if lost for more than three seconds), to name a few. In an embodiment, verifying communication can include receiving a communication within a set time from when a last communication was received. For instance, if communications are supposed to be received every two seconds, and there is a three second gap between receipt of two consecutive communications, the method **400** may determine that communication has not been verified. The signal or communication from the central controller can be transmitted via wireless or wired means. In an embodiment, verifying communication can be an active rather than passive operation. For example, a signal such as a challenge can be sent to the central controller, and the communication is not verified until a response is received.

If communication is verified, then the method **400** determines if a shutdown signal has been received in the shutdown signal received operation **408**. A shutdown signal can replace the signal that is being monitored. Alternatively, the shutdown signal can be overlaid or multiplexed onto the signal being monitored. The shutdown signal can be initiated by automatic means, such as a fire alarm. The shutdown signal

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can be initiated by manual means, such as a fireman pushing an emergency shutdown button at the breaker box on a house that is burning.

If the shutdown signal is not received, then the method 400 can loop back to the perform system checks operation 402 as illustrated. Alternatively, the method 400 can continue to verify communication with the central controller via the verify decision 406. If the shutdown signal is received, then the method 400 shuts the solar module down in the shutdown operation 410. Shutdown may include using a watchdog and/or switchable connection to disconnect the solar module from the power bus. Shutdown may include using a watchdog and/or switchable connection to lower the solar module voltage to a safe level.

After shutdown, the method 400 waits for a restart signal. The restart signal is a signal from the central controller that is transmitted via the same wireless or wired means that communicates the originally monitored signal. The restart signal may be automatically transmitted when certain conditions are met or may be manually initiated. For instance, at the end of a fire or after a home has been fixed after a fire, maintenance personnel may flip a manual switch near the fuse box to initiate the restart signal. In an embodiment where the system is running off of a limited backup power source, the backup power source may run down while the method 400 waits for the restart signal. In this case, the method 400 can initiate a full shutdown. The full shutdown may include turning off all systems which are still operational. When the restart signal is received, the method 400 can loop back to the initialize parameters operation 402.

Returning now to the verify communication decision 406, if communication with the central controller cannot be verified, then the method 400 may continue trying to verify communication until a threshold is surpassed. This continued attempt to verify takes place via the number of skips allowed decision 414. Skips refers to the event of missing a communication or pulse. If a communication or pulse should be received every second, but one pulse is not received, then a skip has occurred. For example, if a communication or pulse is not received for five seconds, then four skips have occurred. Additionally, the threshold can take many forms. For instance, the threshold can be a number of skips. The threshold can be a time period in which communication cannot be verified. The threshold can be a number of missed pulses or a number of pulses having less-than-expected amplitude. These are just a few non-limiting examples of the plethora of thresholds that can be used in the number of allowed skips decision 414. The threshold values can be extracted from or read from a storage medium. The storage medium can be the same one that stores parameters, or it can be a separate storage medium. In either case, non-volatile memory can be used so that the threshold values can still be accessed even after power is lost.

When the threshold is surpassed (or number of skips is exceeded) the method 400 moves to the shutdown and wait operations 410, 412. However, if the threshold is not surpassed (e.g., communication with the central controller is lost, but resumes before the threshold is surpassed), then the method 400 determines if the communication (or signal) includes a shutdown signal via the shutdown decision 408.

One skilled in the art will recognize that the order of operations of the method 400 can be varied without departing from the spirit of the disclosure. At the bare minimum the method 400 requires the verify communication decision 406 along with the shutdown operation 410. Thus, in the broadest sense, the method 400 is about monitoring communication from the central controller, verifying the communication, and shutting

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the solar module down when the communication cannot be verified. Any one or more of the other operations and decisions can be added to this basic set of decision 406 and operation 410. As for different orders of operation, the method 400 can look for the shutdown signal via the shutdown decision 408 concurrently with the verify decision 406 or before the verify decision 406. The number of allowed skips exceeded decision 414 may also operate before, after, or concurrently with the shutdown decision 408. Furthermore, once a restart signal has been received, the method 400 may loop back to the verify decision 406 rather than the initialize and perform operations 402, 404.

FIG. 5 illustrates another embodiment of a method of controlling the output of a solar module. The method 500 may be computer-implemented, and each of the operations discussed below can be carried out via a computing device. The method 500 monitors a signal from a central controller in a monitor operation 502. The method 500 determines if the signal has been lost via a signal lost decision 504. If the signal is lost, then one or more solar modules are disconnected from a power bus via a disconnect operation 508. Disconnect means that a switchable connection has a reduced duty cycle such that the voltage provided to the power bus by the solar module is reduced. In an embodiment, the switchable connection can have a duty cycle of 0%, always open, such that no voltage is provided to the power bus. The method 500 may also determine if the signal includes a shutdown signal via a shutdown signal received decision 506. If the signal includes a shutdown signal, then the method 500 disconnects one or more solar modules from the power bus via the disconnect operation 508. If a shutdown signal is not received, then the method 500 continues to monitor the signal from the central controller via the monitor operation 502. When the one or more solar modules are disconnected from the power bus, the method 500 may optionally enable a bypass circuit via an enable bypass circuit operation 510. The bypass circuit allows current to continue to flow in the power bus when the one or more solar modules are disconnected from the power bus. The method 500 may then wait for a restart signal via a wait operation 512. The method 500 continues to wait for the restart signal until the restart signal is received or until a backup power source (e.g., battery or capacitor) runs out, assuming the primary power source is not available. If the backup power source runs out, then the method 500 initiates a full shutdown. If the restart signal is received, then the method 500 can connect the one or more solar modules to the power bus via a connect operation 516.

By lost signal, it is meant that the signal amplitude is not great enough to surpass an amplitude threshold or that the signal has become so irregular as to surpass an irregularity threshold. For instance, if only ten out of a hundred pulses have been received (assuming a pulsed signal), then the signal may be considered lost.

In an embodiment, watchdog units can be coupled between each solar module and the power bus. The watchdog units can be configured to monitor a signal from a central controller and disconnect the solar modules from the power bus if the signal is lost or if the signal includes a shutdown signal. However, there may not be a watchdog unit for each solar module. In such an embodiment, solar modules that are not coupled to a watchdog unit may not be disconnected from the power bus.

Disconnecting one solar module from the power bus may include a complete disconnection, as for example performed via the opening of a mechanical or electronic switch. However, disconnecting can also include lowering the voltage (e.g., lowering a duty cycle of a switch). One skilled in the art

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will recognize that the order of operations of the method 500 can be varied without departing from the spirit of the disclosure.

It is clear that many modifications and variations of these embodiments may be made by one skilled in the art without departing from the spirit of the novel art of this disclosure. For example, instead of including the watchdog units with the junction boxes, the watchdog units can be a part of local management units (LMU's) that are also responsible for balancing the currents between solar modules in a power bus and are responsible for balancing the voltages between power buses in a solar array. These modifications and variations do not depart from the broader spirit and scope of the invention, and the examples cited herein are to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A system comprising:
 - a watchdog unit coupled between a solar module and a power bus, the power bus configured to connect a plurality of solar modules to an inverter, the watchdog unit having:
 - a local controller configured to monitor a communication from a central controller remote from the solar module and determine whether the communication has been interrupted for a time period longer than a predetermined number of allowed skips; and
 - at least one switch configured to disconnect the solar module from the power bus in response to a determination by the location controller that the communication from the central controller has been interrupted for a time period longer than the predetermined number of allowed skips;
 - wherein the watchdog unit is configured to connect the solar module to the power bus when the communication is not interrupted.
2. The system of claim 1, further comprising a junction box housing the watchdog unit, the junction box to provide connectivity between the solar module and the power bus.
3. The system of claim 2, wherein the local controller is configured to control a duty cycle of the switch to control an output voltage from the junction box.
4. The system of claim 3, wherein the local controller is configured to operate using power from the solar module.
5. The system of claim 1, further comprising a bypass circuit configured to enable current in the power bus to bypass the solar module when the switch disconnects the solar module from the power bus.
6. The system of claim 1, wherein the watchdog unit is configured to determine irregularity in periodicity of the communication to determine whether the communication is interrupted.
7. The system of claim 1, wherein the communication is interrupted when a threshold of irregularity is surpassed.
8. The system of claim 1, wherein the communication is interrupted when the central controller fails to send a communication.

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9. The system of claim 1, further comprising the solar module; and
- a junction box coupled with the solar module to provide connectivity to the power bus, wherein the watchdog unit resides in the junction box.

10. The system of claim 1, further configured to disconnect the solar module from the power bus when the watchdog unit receives a shutdown signal.

11. The system of claim 1, wherein the watchdog unit wirelessly communicates with the central controller.

12. A system comprising:

- a watchdog device coupled between a solar module and a power bus, the power bus configured to connect a plurality of solar modules to an inverter, the watchdog device configured to:

verify communication with a central controller remote from the solar module; and

shutdown the solar module from the power bus if communication with the central controller cannot be verified for a time period longer than a predetermined number of allowed skips.

13. The system of claim 12, wherein to shutdown the solar module entails disconnecting the solar module from the power bus.

14. The system of claim 12, wherein to verify communication:

- a challenge is sent to the central controller; and
- a response to the challenge is received.

15. The system of claim 12, wherein to verify communication, a communication is received within a set time from when a last communication was received.

16. The system of claim 12, further configured to shutdown the solar module if a shutdown signal is received.

17. The system of claim 12, further configured to wait for a restart signal.

18. The system of claim 12, further configured to draw energy from a backup energy source when a primary energy source is not available.

19. A computer-implemented method comprising:

- monitoring, via a computing device, a signal from a central controller remote from the computing device;
- determining, via the computing device, if the signal has been lost more than a predetermined number of times;
- disconnecting, via the computing device, one or more solar modules from a power bus if the signal has been lost more than the predetermined number of times, the power bus configured to connect a plurality of solar modules to an inverter;

waiting, via the computing device, for a restart signal; and connecting, via the computing device, the one or more solar modules to the power bus when the restart signal is received.

20. The method of claim 19, further comprising:

- enabling, via the computing device, a bypass circuit when the one or more solar modules are disconnected from the power bus, so that current continues to flow in the power bus.

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